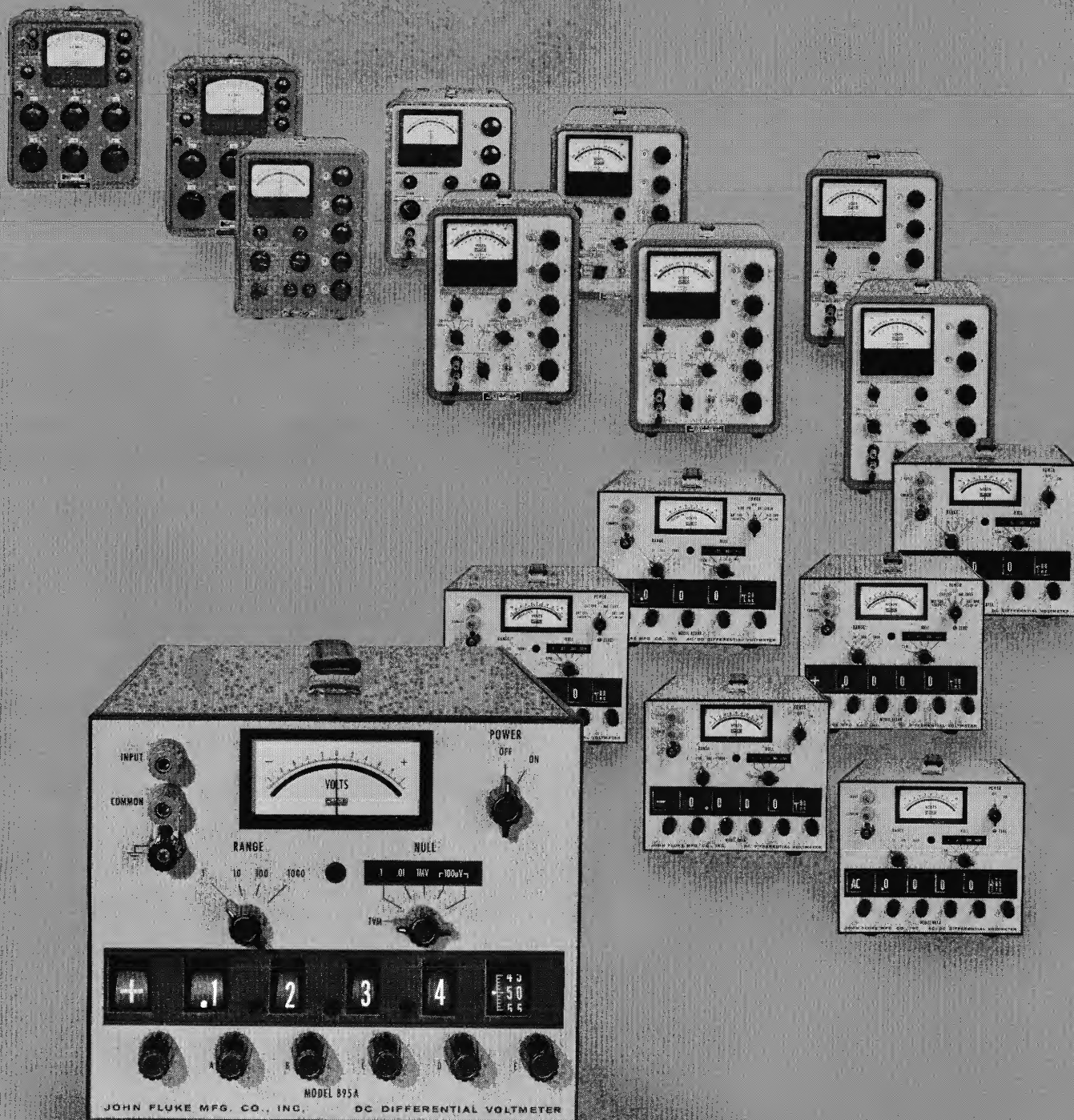


**THE
FLUKE**

STANDARD

APRIL 1967 VOL.1 NO.1



THE FLUKE STANDARD

"A Service to Industry"

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ON THE COVER

The cover portrays the history of the differential voltmeter. Featured in the foreground is the Fluke Model 895A, the first solid-state instrument with an 1100-volt reference supply. Accuracy is 0.0025% of input. In the background are its predecessors beginning with the Fluke Model 800—the first differential voltmeter. It revolutionized the field of dc measurement in 1955 by making standards lab accuracy of 0.05% and infinite input impedance available for general laboratory and production use. Among the others shown are the Model 885-AB with 0.0025% dc accuracy and battery power; the Model 887AB with 0.0025% dc accuracy and 0.05% ac accuracy; and the familiar Model 803, the first ac/dc differential voltmeter.

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DEDICATION

Frequently in the course of our work at John Fluke Mfg. Co., Inc., we discover or develop information and techniques of value which should be shared with the engineering community. We have a guideline which is used to evaluate new products — *each new instrument must offer a significant advancement in accuracy, versatility, or ease of operation*. Such advancements in instrumentation are the results of state-of-the-art advancements in the techniques of design, manufacturing, and testing.

In the development of our instruments we are always conscious of the user. From the beginning of the Company, ease and speed of operation have been considered no less essential than accuracy and stability. An instrument by itself can accomplish nothing; it is a tool; its effectiveness depends on the user. The service that a skilled craftsman obtains from his tools depends on his knowledge of them and of the techniques for using them.

For the benefit of our readers we shall discuss information of technical interest, particularly advancements in the state-of-the-art, calibration techniques, and measurement techniques. This information will be furnished, not only to increase our readers' knowledge of our instruments, but also to enhance their understanding of electrical measurement. Thus, *to the service of our readers THE FLUKE STANDARD is dedicated.*

MEET THE AUTHORS



PAUL BEIHL

Paul Beihl joined Fluke in 1963 with five years of experience in the design of analog circuits, power control circuits, computer circuits, regulated power supplies, and ground support and checkout equipment. His accomplishments in the differential voltmeter group were made primarily as design leader for the Model 873A and the Model 895A. He recently transferred to the Company's subsidiary, Montronics, Inc.

Paul received his BS degree in Electrical Engineering at Purdue University. He has taken graduate engineering courses at the University of Southern California and the University of California at Los Angeles. Paul is a member of IEEE and a Licensed Professional Engineer in the State of Washington. He holds a patent on a regulator control circuit.



PAUL HAUGE

Paul Hauge is Section Head responsible for all Fluke instruments. Previously as Project Engineer and later as Group Leader, he was responsible for the development of the line of solid-state differential voltmeters including the Model 895A. His initial assignments, after joining Fluke in 1960 with four years' experience in the design of test instrumentation, were development of special power supplies and vacuum tube differential voltmeters.

Paul graduated from Purdue University in 1956 with a BS degree in Electrical Engineering. He received his MS degree in Electrical Engineering at Stanford University in 1958. His memberships include Tau Beta Pi, Eta Kappa Nu, and IEEE.

THE FLUKE STANDARD



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NEW DIFFERENTIAL VOLTMETER

The First Solid-State Instrument with Infinite Input Resistance to 1100 Volts

Differential voltmeters with infinite input resistance at null cause no loading effect on the source being measured. This very desirable feature (true potentiometric measurement) results from using a highly stable, extremely accurate, internal high-voltage reference to exactly match the voltage being measured. The fixed output of an internal high-voltage supply is divided to the value of the measured voltage by a high-resolution voltage divider of the Kelvin-Varley type. The difference between the measured voltage and the reference voltage is detected by a sensitive null detector. This has been the proven means of achieving infinite input resistance in the Fluke line of vacuum tube differential voltmeters.

With the advent of solid-state instruments significant improvements were made in terms of greater portability, higher accuracy, and improved reliability. Input resistance was infinite from 0 to 11 volts and 10 megohms from 11 volts to 1100 volts. Now, the Model 895A combines the advantages of a high-voltage supply and solid-state circuitry to yield accuracy of ± 25 ppm ($\pm 0.0025\%$) of input, plus infinite resistance at null over the entire range of 0 to ± 1100 volts. New

features introduced with this instrument include ratiometer capability, 100-megohm input resistance in TVM (transistor voltmeter or direct reading) mode, and a recorder output adjustable from 0 to 0.5 volt that is referenced to chassis ground. Switching the polarity of the voltage supply at the input to the Kelvin-Varley divider allows measurement of negative and positive voltages under the same conditions regardless of external grounding.

In addition to the primary application as a ± 25 ppm voltmeter and the secondary application as a ± 12 ppm ratiometer, this new differential voltmeter also may be used as a megohmmeter or as a sensitive, high-gain, dc amplifier. The internal 1100-volt reference permits measuring leakage resistance typically to better than 10^{13} ohms by connecting the resistance to be measured across the input binding posts. The same means may be used to measure leakage current of capacitors and of wiring insulation with an impressed voltage of 0 to 1100 volts dc. Signals from dc to 2 Hz may be amplified with a voltage gain of up to 5000 by utilizing the recorder output. Linearity of the recorder output is 0.5% of end scale and maximum output voltage is ± 0.5 volt.

Accuracy and Stability

Absolute accuracy is specified in terms of the theoretical standards maintained by the National Bureau of Standards. When specifying the absolute accuracy of an instrument, the uncertainty of the calibration equipment must be included in the specification as it is with the Model 895A. The practical limit of calibration accuracy traceable to NBS over the range of 0 to 1100 volts dc is an uncertainty of ± 10 ppm. This includes the uncertainty of the certification (± 2 ppm) of a temperature-controlled bank of standard cells and the accumulated uncertainties of available ratio devices and a high-voltage source. The absolute accuracy of the working standards used for factory calibration of 25 ppm Fluke differential voltmeters is traceable to NBS with a maximum uncertainty of 10 ppm ± 2 uv.

Absolute accuracy of the Model 895A is $\pm (25$ ppm of input + 1 ppm of range + 5 uv) from 0 to 1100 vdc at nominal calibration temperature and up to 70% relative humidity. At any temperature within the range of 16°C to 32°C, absolute accuracy from 0 to ± 1100 volts is $\pm (50$ ppm of input + 5 uv).

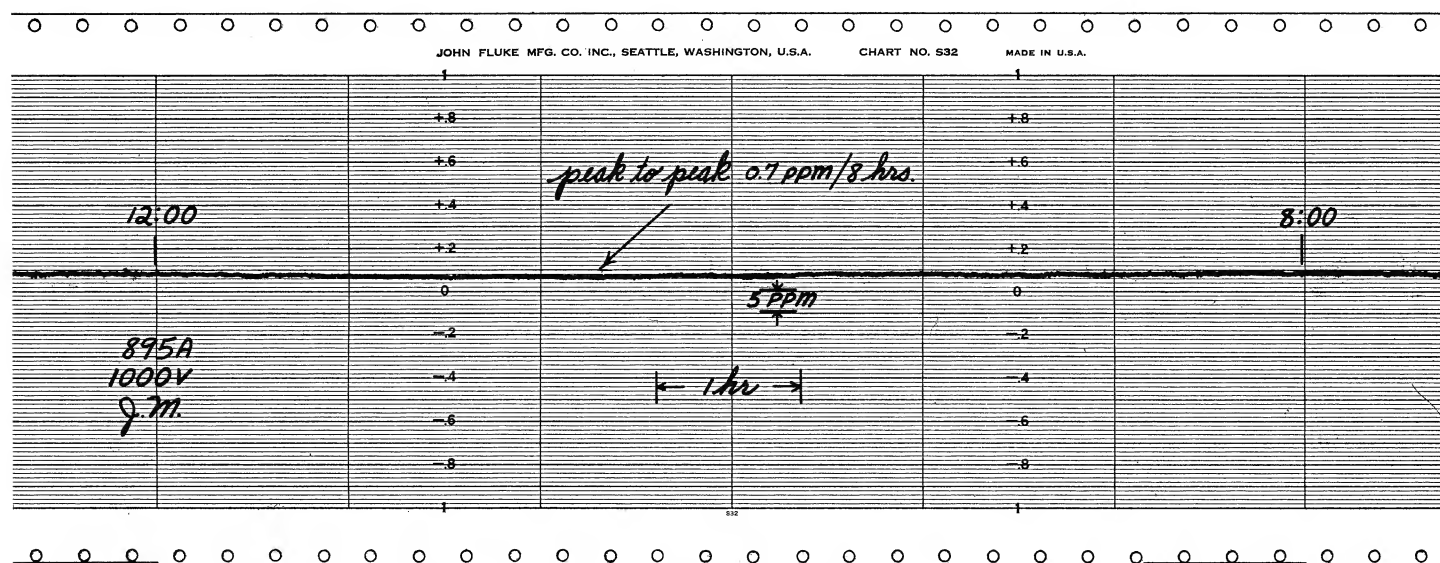


Figure 1. Instrument Stability. Recorded over an 8-hour period, stability is approximately 0.7 ppm peak-to-peak. Measured source is 1000v referenced to an unsaturated standard cell.

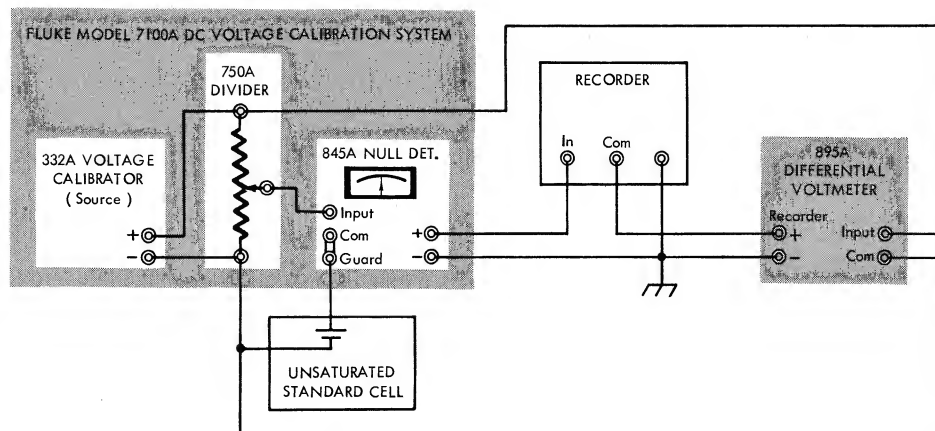


Figure 2. Stability Set Up. Voltage source (Fluke Model 332A) is referenced to unsaturated standard cell through Fluke Model 750A Reference Divider. Recorder output of Null Detector/Microvoltmeter (Fluke Model 845A) is used as a bucking voltage to recorder. This set up compensates the recording for any fluctuation in the voltage source.

Accuracy of an instrument at any given time depends upon the accuracy of calibration and upon the stability of the instrument. The typical long term stability of the Model 895A is better than 20 ppm peak-to-peak per year permitting the instrument to meet all specifications when recalibrated only once a year.

Short term stability of the instrument is typically better than 2 ppm peak-to-peak per hour and 3 ppm peak-to-peak per 8-hour period. Figure 1 is a strip chart recording of stability measuring a precise 1000 volts dc for an 8-hour period. The equipment set up for the stability measurement is shown in Figure 2.

Ratiometer Mode

A new and unique feature of the 895A is its capability of functioning as a true ratiometer. Voltage and resistance ratios are compared within ± 12 ppm by placing the Model 895A in the ratio mode of operation, which disconnects the internal high-voltage reference from the Kelvin-Varley divider and connects the 1.0 tap of the Kelvin-Varley divider to the ratio input terminal on the rear panel. This establishes a means of comparing two voltages of up to 1000 volts. To accomplish the comparison, the higher voltage is connected to the ratio input, the lower voltage is connected to the voltmeter input and the voltage dials are adjusted to obtain a meter null. The setting of the voltage dials at null is the ratio of the lower voltage to the higher voltage with .9999100 representing unity. For comparison of resistance ratios, the connections are made as shown in Figure 3. No power

derating of the Kelvin-Varley divider is required for ratio measurements up to 1000 volts. For calibration of other voltage dividers or potentiometers, a null is obtained at each point of comparison. The device being calibrated may be adjusted to read the same as the Model 895A, or the difference between readings may be recorded in a table of corrections.

Theory

The Model 895A consists of a null detector and a 0 to 1100 volt reference. (See block diagram, Figure 4.) A switched attenuator at the input of the null detector attenuates the input voltage to match it to the sensitivity of the null detector. End scale null deflection (difference between unknown voltage and internal reference voltage) is 100 μ v to 100v in seven ranges. Null range switching is automatic with instrument input range switching so that maximum meter resolution is a constant 0.1 ppm of range above 1 vdc. Below 1 vdc, maximum meter resolution is 1 ppm of range (1 μ v). The null detector and voltage reference circuits are switched to provide the basic voltmeter functions in null and TVM modes of operation.

In null mode of operation, null detector common is connected to the output of the reference—null detector common may be at any level from 0 to 1100 volts. Sensitivity of the null detector circuit is 100 μ v for full scale deflection of the meter. Null detector noise is reduced so that it can not be observed on the meter by reducing the sensitivity to 1 millivolt full scale except for the 100 μ v null range. Because the null attenuator is referenced

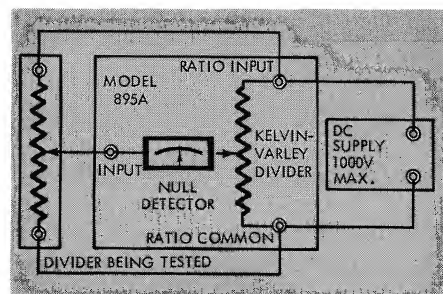
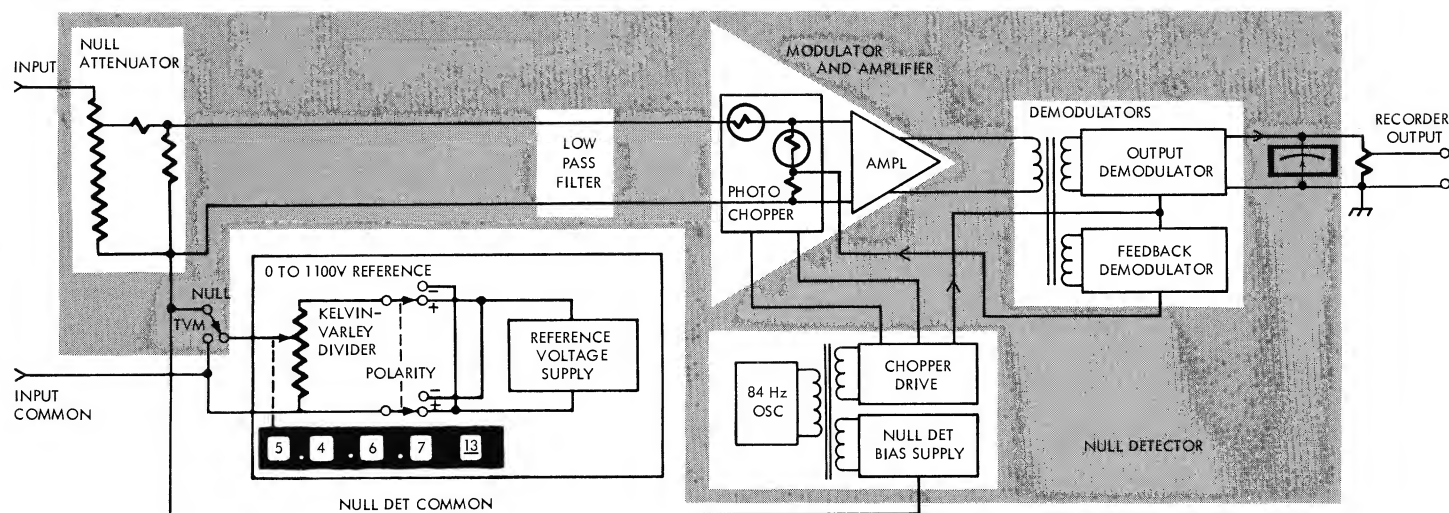


Figure 3. Comparison of Resistance Ratios. Divider being tested and the Kelvin-Varley divider of the Ratiometer are connected in parallel between the output terminals of the voltage supply. The null detector compares the output of the dividers. At null, the readout dials of the Model 895A indicate the actual resistance ratio of the unknown divider.

to null detector common, it divides the difference between the input and the reference voltage to match null range to detector sensitivity. Current flow through the attenuator resistance is determined by the difference between the input voltage and the internal reference voltage. At null these voltages are equal and input resistance is essentially infinite. The input resistance of the null detector is 100 megohms for null ranges of 100 volts through 100 millivolts, 10 megohms for the 10-millivolt range, and 1 megohm for the 1-millivolt and 100-microvolt ranges. Because of the high input resistance on all null ranges, extremely high input resistance is maintained for off-null deflections. This is important when measuring voltage excursions around a null—one of the prime applications of a Fluke differential voltmeter. Figure 5 shows the off-null input resistance of the instrument in ohms per volt.

In the TVM mode of operation, the 0 to 1100 volt reference is disconnected and null detector common is connected to input common. This causes the null attenuator to divide the total input voltage down to match the sensitivity of the null detector. In this configuration the null detector functions as a direct-reading voltmeter. TVM ranges are 1000 v, 100 v, 10 v, and 1 v, each with 10% over-ranging. The input resistance on all ranges is the 100 megohms of the input divider. Although the lowest TVM range is 1 volt, the null ranges of 0.1 volt to 0.0001 volt full scale may be used as extended TVM ranges by turning all voltage dials (setting the Kelvin-Varley divider) to zero.



Null Detector

The null detector is a current feedback amplifier which drives a taut-band, zero-center meter. It consists of the null attenuator and input filter, a full-wave photocell modulator, a high-gain ac amplifier, demodulators, and chopper drive circuits. The input dc signal is modulated by the photocell chopper and ac coupled to the ac amplifier. The output of the amplifier is coupled by an isolation transformer to two separate demodulators. One demodulator is referenced to chassis ground and drives the meter and the recorder output. The other demodulator is referenced to null detector common and provides a feedback signal to the input modulator to stabilize the forward dc gain of the null detector.

The chopper drive circuit provides ac drive for the photochopper modulators and the transistor demodulators. It also furnishes the isolated bias voltages required by the null detector. Driving power for the neon lamps, which illuminate the photocells, is furnished by a secondary winding of the chopper drive transformer. Driving signals for the two demodulators are taken directly from separate windings of the transformer. The bias voltages for the null detector are obtained by rectifying and filtering the output of another secondary winding. This section of the chopper drive circuit functions as a dc-to-dc converter with a regulated input. The chopper drive oscillator is a transformer coupled RC multivibrator operating at 84 Hz, a frequency selected to eliminate beating with line frequency or submultiples of line frequency.

Great care in transformer design and the development of special manufacturing processes were required to obtain the isolation to 1100 vdc necessary to eliminate leakage paths, which would affect the accuracy of the instrument.

Recorder Output

The grounded recorder output permits the use of any standard laboratory recorder with the Model 895A. An isolation transformer in the null detector, prior to the output demodulator, allows demodulation at ground potential. Recorder output, which is directly proportional to meter deflection, may be adjusted from 0 to ± 0.5 vdc.

0 to 1100 Volt Reference

In a true potentiometric instrument, accuracy of measurement depends directly upon the accuracy and stability of the internal voltage reference. The internal 0 to 1100 volt reference of the Model 895A (Figure 6) consists of a +18-volt regulated supply, an 1100-volt supply, a range switch and range dividers, a polarity switch, and a Kelvin-Varley divider. The primary reference for regulation of the voltage supplies is a matched pair of selected preconditioned Zener diodes.

Low-voltage operating power for the instrument is furnished by the auxiliary +18-volt regulated supply, which consists of a compound differential amplifier driving a series regulator. The Zener reference diodes are located in an error-sensing bridge at one input to the differential amplifier. The auxiliary supply is used as a driving source for the Zener reference diodes,

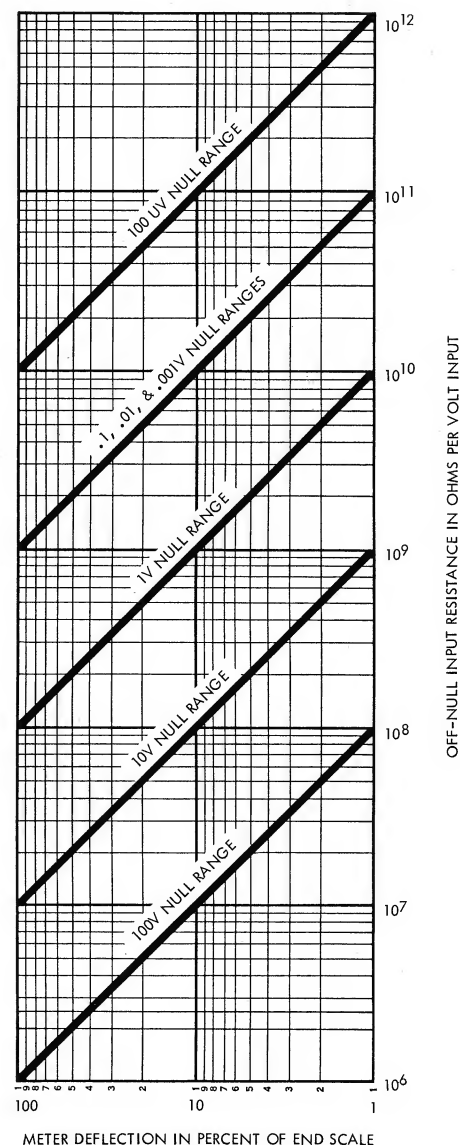


Figure 5. Off-null Input Resistance.

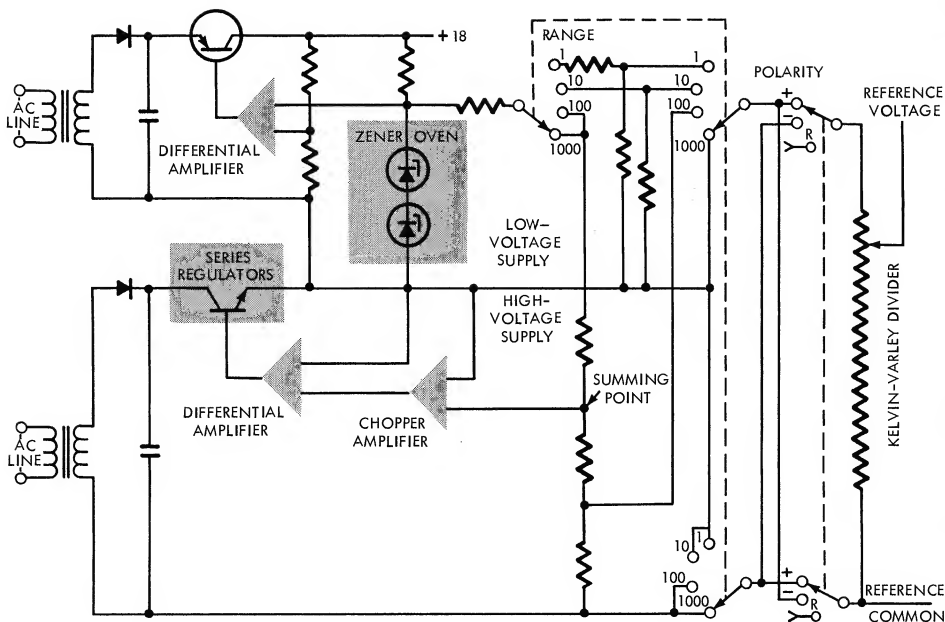


Figure 6. 0 to 1100 Volt Reference. Low-voltage supply and high-voltage supply are referenced to one pair of Zener diodes. High-voltage supply is stabilized by chopper amplifier. Kelvin-Varley divider provides 6-digit resolution of reference voltage. Polarity is switched at input to Kelvin-Varley divider.

as regulated bias in the 1100-volt supply, and as power for the chopper drive circuit. The Zener voltage is used directly as the voltage reference for the 1-volt and 10-volt ranges and as the primary reference of the high-voltage supply on the 100-volt and 1000-volt ranges. The Zener voltage is compared with the 1100-volt reference through a precision 1:100 feedback resistance ratio. The error signal developed by the feedback divider is amplified by a high-gain, chopper-stabilized amplifier. The high gain of the chopper amplifier reduces the temperature or drift effect within the amplifiers. The dc error signal at the summing point (Figure 6) is chopped by a photocell modulator driven by the same light source as the null detector modulator. At the output of the chopper amplifier, it is demodulated by a transistor switch producing an amplified dc level proportional to the dc error signal. This dc level is applied to the differential amplifier, which in turn controls the series regulators.

The unique design of the series regulator section (Figure 7) employs high-voltage transistors (Q1 and Q2) as preregulators, and a low-voltage transistor (Q4) for optimum regulation and stability. Although the voltage drop across Q1 and Q2 may range from approximately 35 volts to over 600 volts, the collector of Q4 is clamped to the +18-volt supply through the base-emitter junction of

Q2. The use of the preregulating loop reduces its change in output voltage for a given line voltage change by a factor of about a million to one. Regulation of the 1100-volt reference supply, specified at ± 2 ppm for a 10% line voltage change, typically measures better than ± 1 ppm.

Low-Mass Zener Oven

Extreme stability and fast reference warm up are achieved through the use of a low-mass, proportionally controlled Zener oven which stabilizes within one minute after turn-on. The oven control circuit consists of a differential pair of transistors used as a null detector in a resistance bridge. One element of the bridge is a thermistor that is enclosed in the oven with the heater resistor and the matched Zener diodes. The output of the differential amplifier drives a current amplifier, which provides power to the oven heater thereby maintaining the oven temperature at a preset level.

Kelvin-Varley Divider

The Kelvin-Varley divider consists of four decades and a precision vernier potentiometer. Four digits are read from the decade switch dials and two are read from the potentiometer for six-digit resolution. Self-heating and its effect on linearity are minimized by the very high divider resistance of 440 kilohms, which limits divider

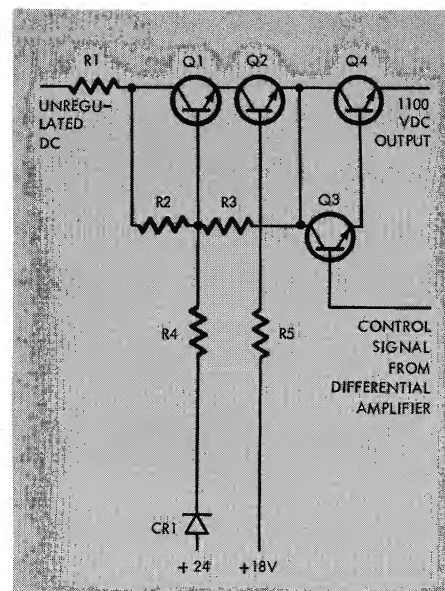


Figure 7. High-Voltage Series Regulators. High-gain transistor, Q4, is series regulator. High-voltage transistors, Q1 and Q2, function as preregulators.

current to 2.5 ma at 1100 vdc. Heating effect is further reduced by the use of a series combination of two resistors in each step of the first decade. These precision resistors are unique, stress-free, bobbin-type, wirewound units of Fluke design and manufacture. High accuracy and an extremely low temperature coefficient of divider ratio are realized by precisely matching the resistors of each decade for resistance and temperature coefficient (TC) and then matching the decades. In addition, the resistors used in the first decade are selected and paired for equal and opposite TC to yield a total TC of zero for each step. This extremely close matching results in accuracy of ± 12 ppm of setting from 0.1 full scale to full scale. An eleventh step in the first decade provides the 10% over-ranging capability.

Warm-Up

The fast warm-up of the low-mass Zener diode oven permits measurements with accuracy of ± 50 ppm after a period of less than five minutes. A warm-up period of less than 30 minutes stabilizes the Model 895A to achieve ± 25 ppm absolute accuracy. During operation on the lower voltage ranges, the 1100-volt reference supply is turned off and a heater resistor is switched on in its place to maintain constant ambient temperature within the instrument.

—PAUL BEIHL AND PAUL HAUGE

SPECIFICATIONS

Fluke Model 895A DC Differential Voltmeter

As a Differential Voltmeter

ABSOLUTE ACCURACY: $\pm(0.0025\%$ of input $+0.0001\%$ of range $+5\text{ uv}$) from 0 to $\pm 1100\text{ vdc}$ at $23^\circ\text{C} \pm 1^\circ\text{C}$ (nominal calibration temperature), less than 70% relative humidity.

$\pm(0.005\%$ of input $+5\text{ uv}$) from 0 to $\pm 1100\text{ vdc}$, within the temperature range of 16°C to 32°C (60°F to 90°F), less than 70% relative humidity. Derate accuracy outside this temperature range at $0.00035\%/^\circ\text{C}$ to extremes of 0°C and 50°C .

NOTE: Thorough error analysis studies into total instrument stability taking into account the documented stabilities of individual components and utilizing probability and statistical methods, indicate that typical instrument stability (defined as a specification met by 80% to 90% of all instruments) is 20 ppm (0.002%) peak-to-peak per year. An instrument so categorized need be calibrated only once per year to meet all specifications. Additional stability data upon request.

INPUT RANGES: 1, 10, 100, 1000 vdc with 10% over-ranging capability.

NULL RANGES:

Input Range	Null Ranges
1v	0.1, 0.01, 0.001, 0.0001v
10v	1, 0.1, 0.01, 0.001, 0.0001v
100v	10, 1, 0.1, 0.01, 0.001v
1000v	100, 10, 1, 0.1, 0.01v

INPUT RESISTANCE: Infinite at null from 0 to $\pm 1100\text{ vdc}$.

METER RESOLUTION: 1 uv maximum (0.1 ppm of range above 1 vdc, 1 ppm of range below 1 vdc).

VOLTAGE DIAL RESOLUTION: 1 uv maximum (1 ppm of range).

As a Conventional Voltmeter

ACCURACY: $\pm 3\%$ of range.

RANGES AND INPUT RESISTANCE:

1000-0-1000	100 Megohm input resistance
100-0-100	100 Megohm input resistance
10-0-10	100 Megohm input resistance
1-0-1	100 Megohm input resistance
*0.1-0-0.1	100 Megohm input resistance
*0.01-0-0.01	10 Megohm input resistance
*0.001-0-0.001	1 Megohm input resistance
*0.0001-0-0.0001	1 Megohm input resistance

NOTE: 10% overranging capability. *These ranges obtained using null ranges with all readout dials at zero.

As a Ratiometer

CIRCUIT: "RATIO" position of polarity switch places Kelvin-Varley divider across rear panel binding posts for connection to external reference input voltage. Null detector remains between front panel input and Kelvin-Varley variable tap. At null, voltage dial (Kelvin-Varley) setting indicates decimal ratio of front panel input voltage to rear reference input voltage.

RATIO: Zero to unity (six-digit readout).

REFERENCE INPUT VOLTAGE: 0 to $\pm 1000\text{ vdc}$ with no power derating over entire range.

RATIO ACCURACY:

$\pm 0.0012\%$ of setting at 0.1 ratio and above
 $\pm 0.00012\%$ terminal linearity below 0.1 ratio

TEMPERATURE COEFFICIENT OF RATIO:

0.0001% of setting/ $^\circ\text{C}$ above 0.1 ratio
0.00001% terminal linearity/ $^\circ\text{C}$ below 0.1 ratio

General

REGULATION OF REFERENCE SUPPLY: 0.0002% for a 10% line voltage change.

STABILITY OF REFERENCE SUPPLY:

0.0005% peak-to-peak per hour
0.0008% peak-to-peak per day
0.0013% peak-to-peak per sixty days

STABILITY OF METER ZERO (includes noise): $\pm 2\text{ uv}$ for a 10% line voltage change on most sensitive (0.0001v) null range.

KELVIN-VARLEY DIVIDER ACCURACY: $\pm 0.0012\%$ of setting from 1/10 full scale to full scale. $\pm 0.00012\%$ terminal linearity below 1/10 full scale.

REFERENCE ELEMENT: Temperature compensated Zener diodes.

WARM-UP TIME: 30 minutes.

RECORDER/ISOLATION AMPLIFIER OUTPUT: Adjustable from 0 to 0.5v minimum for end-scale meter deflection, source resistance 5k to 8k, linearity better than $\pm 0.5\%$ of end-scale. Gain as an isolation amplifier is (0.5v/null-range sensitivity).

POLARITY: Front panel switch selects +dc, -dc, and ratio.

DC COMMON MODE REJECTION: 140 db or 0.1 uv/volt of common mode voltage.

AC COMMON MODE REJECTION: 140 db at 50, 60, and 120 Hz; 120 db at 400 Hz and 1000 Hz.

OPERATING TEMPERATURE RANGE: 0°C to 50°C (32°F to 122°F).

HUMIDITY: Within specifications up to 70% relative humidity.

STORAGE TEMPERATURE RANGE: -40°C to $+70^\circ\text{C}$ (-40°F to 158°F).

SHOCK: Meets requirements of MIL-T-945A and MIL-S-901B.

VIBRATION: Meets requirements of MIL-T-945A.

INPUT POWER: 115/230 vac $\pm 10\%$, 50 to 1000 Hz, 15 watts, 20 va.

SIZE: 7" high x 8-1/2" wide x 14-3/4" deep.

WEIGHT: 16 lbs.

PRICE: \$1095.00



Located on a 20-acre tract at 7001-220th Street S.W. in suburban Mountlake Terrace north of Seattle, Washington, the John Fluke Mfg. Co., Inc., employs over 600 persons and occupies 92,000 square feet of floor space. Manufacturing facilities include areas devoted to instrument assembly, testing, and the manufacture of circuit boards, transformers, precision resistors, sheet-metal parts, and plastic parts. Separate laboratories are provided for developmental engineering, component testing, environmental testing, standards, calibration, chemical analysis, and photographic processing. A machine shop fabricates special tooling and a printing shop prints catalogs, bulletins, manuals, and all promotional publications. Company standards and critical manufacturing operations are housed in environmentally controlled rooms. A modern computer facility is used for production, inventory, and fiscal control.

John M. Fluke started the Company in 1948 when he hired two employees to produce his invention, an electronic wattmeter called the VAW® Meter, in the

basement of his home. The growth of the Company may be traced directly in terms of advancements contributed to the field of electrical measurement. Each of these contributions has been an order-of-magnitude improvement in the accuracy of available instruments. Such contributions include the original VAW® Meter, the differential voltmeter, and several power supplies of unique design.

Primary product lines now include precision dc and ac/dc differential voltmeters, rms voltmeters, voltage calibrators, frequency synthesizers, frequency comparators, VLF phase comparison receivers, standard frequency distribution amplifiers and systems, and precision high-voltage power supplies. The Company also manufactures accessories for these products, voltage dividers, a general purpose impedance bridge, microvolt potentiometers, and precision decade and vernier potentiometers. The Company's goal from its inception has been to produce instruments of ever increasing accuracy and usability.



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